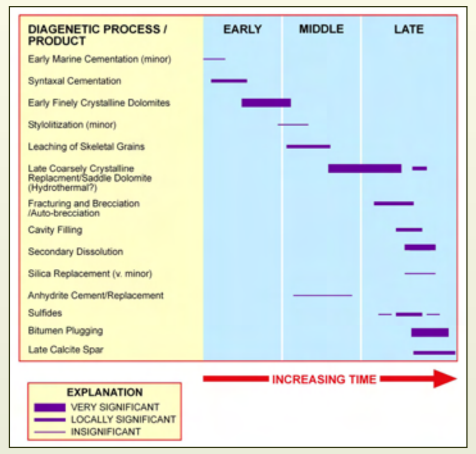
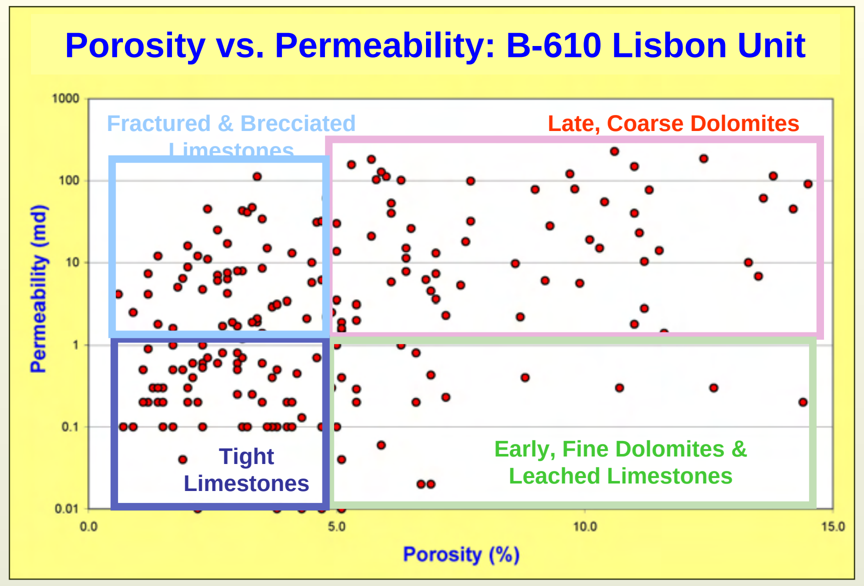
Ideal Diagenetic Sequence Through Time, Leadville Limestone, Lisbon Field, Utah



The early diagenetic history of the Leadville sediments, including some early dolomitization and leaching of skeletal grains, resulted in low porosity and/or low permeablility rocks. Most of the porosity and permeability associated with hydrocarbon production was developed during deeper subsurface dolomitization and dissolution. Some of these important subsurface processes are shown in the purple bars above.



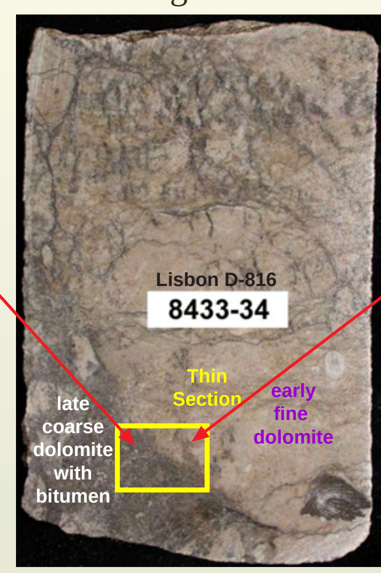
This representative set of core analyses from the Leadville Limestone at Lisbon field shows two distinct populations of dolomites with respect to permeability and petrographic character. The early, finely crystalline dolomites (with or without isolated molds) display low permeability. The coarser late dolomites (with or without late dissolution) display high permeability. Some of these highly permeable dolomites are shown in the photos below.

Dolomitization and Porosity Development in the Leadville Limestone

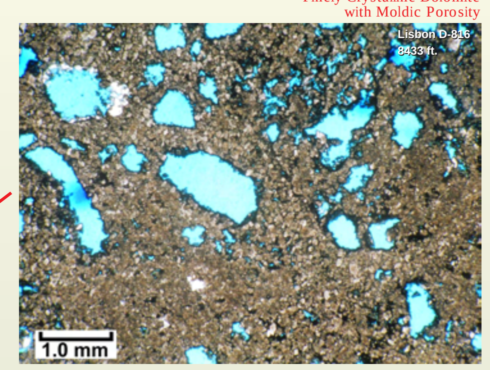
Early and Late Stages of Dolomitization

Coarsely Crystalline Dolomite with Intercrystalline Porosity & Pyrobitumen

Representative plane light view of coarser replacement dolomite (both euhedral rhombs and occasional "saddle" overgrowths). The black (opaque) areas are the result of pyrobitumen films and minor sulfide precipitation.



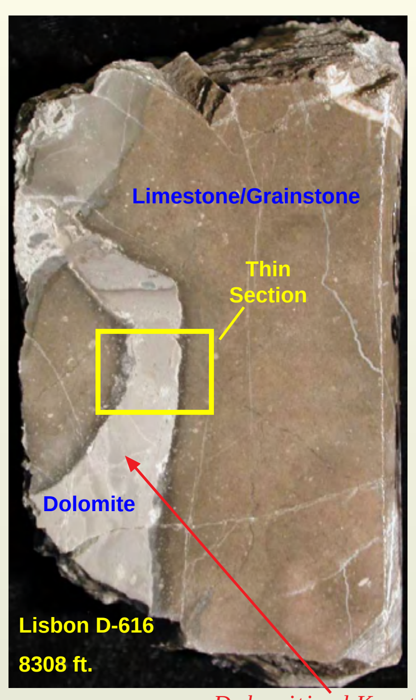
Finely Crystalline Dolomite with Moldic Porosity



Representative view of the tight, finely crystalline dolomite with isolated grain molds. Most of this fabric selective dolomite formed early in the diagenetic history of the skeletal/peloid sediment.

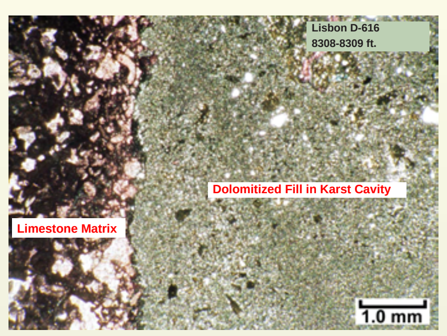
Conventional core slab showing tight, fabric selective, very fine early dolomite as well as porous, coarser late dolomite. Most of the late dolomite crystal faces are coated with films of pyrobitumen. Hence, most of the areas of crosscutting coarser dolomites are black in this view. Note the position of the thin section which captures the contact between low-permeability early dolomite (upper right part of the thin section box) and high-permeability late, "black dolomite" (lower left).

Karst-Related Processes

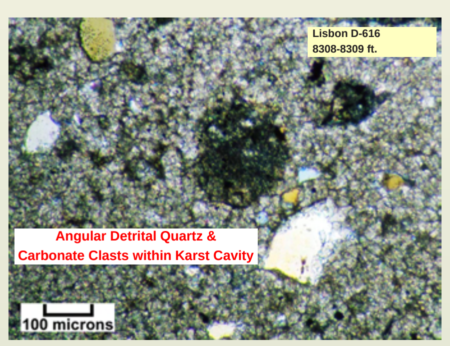


Dolomitized Karst Infill

Sediment-filled cavities are relatively common throughout the upper third of the Leadville Limestone in Lisbon field. These cavities were related to karstification of the exposed Leadville. Infilling of the cavities by detrital carbonate and siliciclastic sediments occurred before the deposition of the Pennsylvanian Molas Shale. The carbonate muds infilling the karst cavities were largely dolomitized.

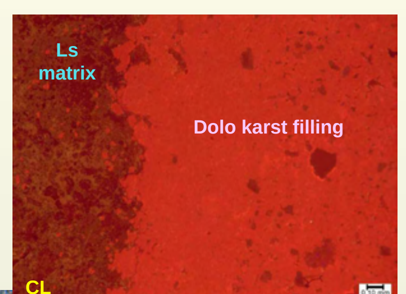


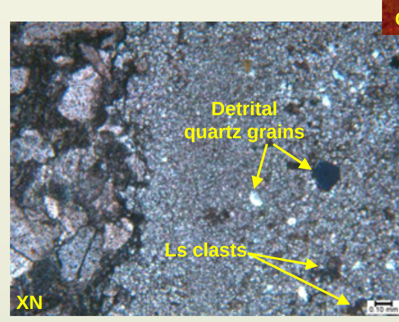
Low magnification micrograph under plane light showing the contact between the non-porous limestone matrix and the non-porous dolomitized and siliciclastic karst-cavity filling.



Higher magnification of detrital quartz grains (white and yellow) and small carbonate clasts (dark gray) within the tight, dolomitized mud filling the karst cavity.

Catholuminescence of Dolomitized Karst Filling



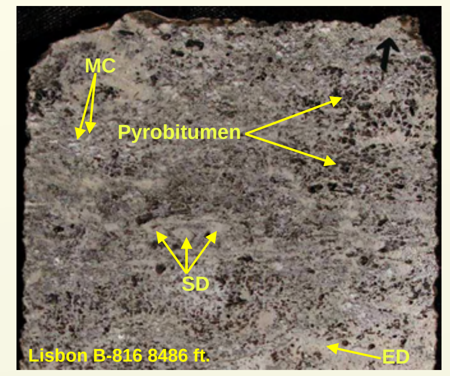


Lisbon D-616

8308 ft.

The upper right micrograph shows the contact between the limestone matrix (in dark red) and the dolomitized karst filling (in bright red) under catholuminescence (CL). Note that the dolomitized filling is composed of very fine crystals displaying uniform red CL colors. The identical view under crossed nicols (XN) is shown in the lower left.

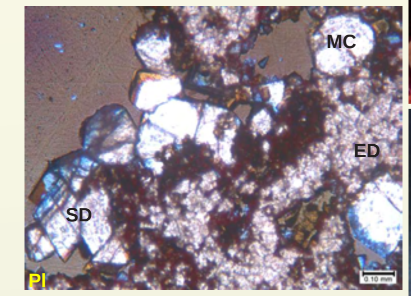
Coarse Replacement and Saddle Dolomites

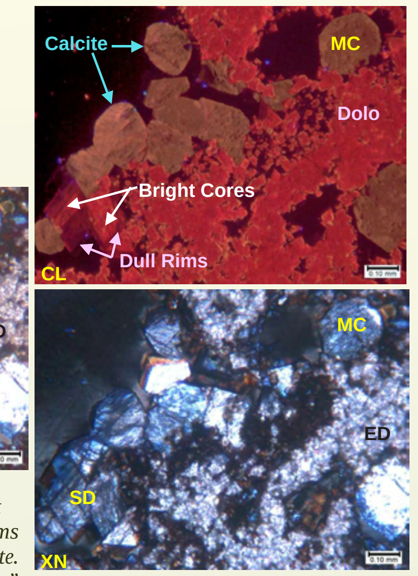


Conventional core surface showing a typical interval in which fabric selective, early dolomite (ED) is replaced by much coarser, rhombic dolomites (with excellent permeability). Some replacement dolomites also display saddle dolomite (SD) morphologies. Most of the coarser dolomites are lined with thin films of black pyrobitumen. A few dissolution pores are filled with post-coarse dolomite macrocalcite (MC) cements.

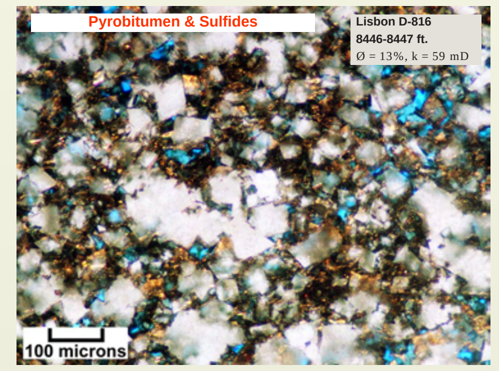
CL of Coarse Replacement and Saddle Dolomites

Lisbon B-816, 8486 ft.





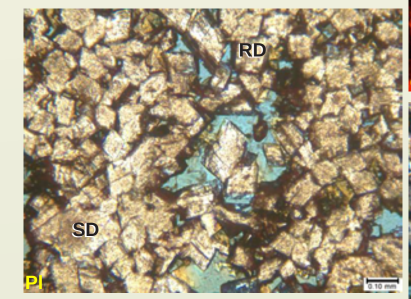
CL shows bright red luminescing replacement dolomite (upper rt. view) cores with frequent rims (overgrowths) of dull to non-luminescent dolomite. Some of these zoned dolomites develop "saddle" characteristics (see plane light [Pl] & crossed nicols [XN] pairs of the same field of view).

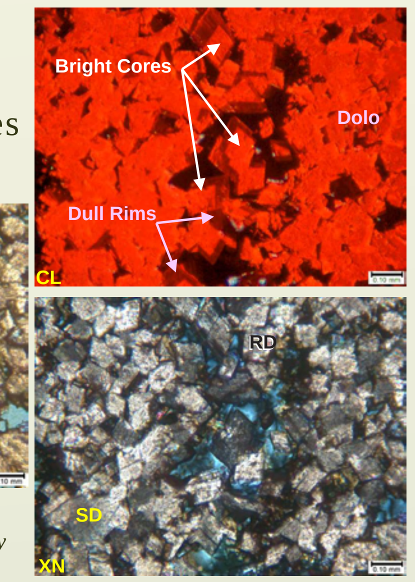


Thin section micrograph under "white card" and reflected light showing black pyrobitumen and sulfide minerals on and between rhombic dolomite crystals (in white and light gray).

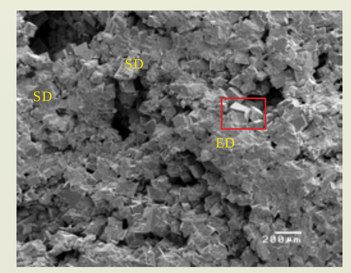
Zoned Replacement and Saddle Dolomites

Lisbon D-816, 8433 ft.

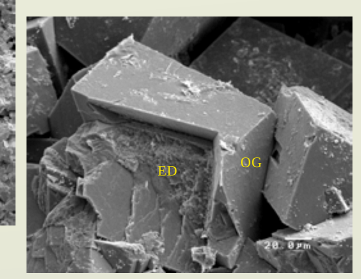




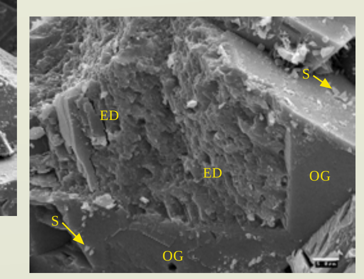
CL view (in upper right) of replacement rhombic (RD) and saddle (SD) dolomites. Note that many of the replacement dolomites display bright cores and dull rims. The same field of view is shown under plane and crossed nicols light.



A



B



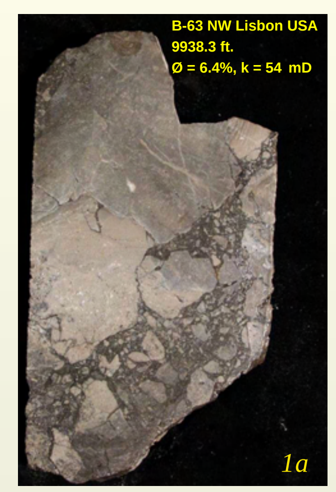
C

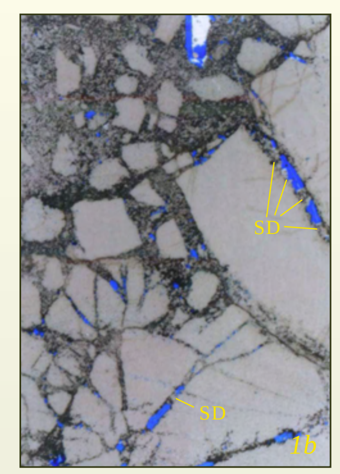
A. Low magnification SEM showing typical Leadville dolomites at Lisbon field. Note the very fine, tight early dolomites (ED) that have been replaced with late rhombic and saddle (SD) dolomites. There is significant porosity increase associated with the late dolomite replacement. Red box = B.

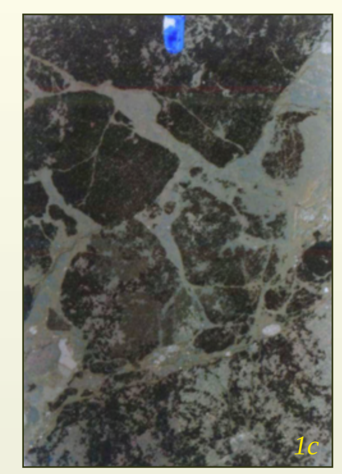
B. This closer view shows the composition of typical replacement rhombic dolomites. The core of each rhombic crystal is composed of a dense remnant of fine, early dolomite (ED) which is surrounded by a euhedral dolomite overgrowth (OG). The rhombic dolomite faces are often covered with a thin film of pyrobitumen.

C. High magnification SEM across a section of a poorly crystalline, early dolomite core (ED) and a dense overgrowth (OG) that forms the dolomite into coarser rhombs. The very small angular decorations on the crystal surfaces may be very small sulfide precipitates (S).

Post-Burial Brecciation, Dissolution & Cements





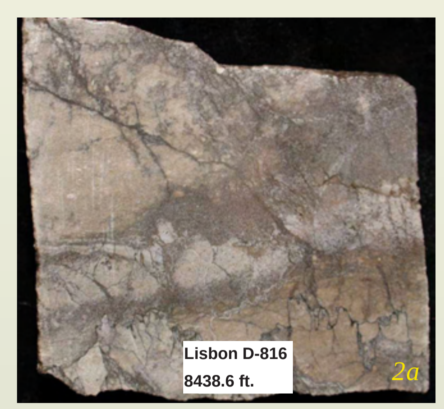


Fracturing and brecciation are quite common in late dolomites within Lisbon field.

1a. Core photo showing a dolomite "autobreccia" in which the "clasts" have moved very little. The black material surrounding the in-place "clasts" is composed of porous late dolomite coated with pyrobitumen.

1b. Entire thin section overview of low-porosity white dolomite clasts surrounded by solution-enlarged fractures partially filled with coarse rhombic and saddle dolomites that are coated with pyrobitumen. These black areas between the clasts exhibit very good intercrystalline porosity. The open fracture segments (in blue) between clasts are bridged by coarse saddle dolomite (SD) cements. Width of thin section is 2.5 cm.

1c. Entire thin section overview of black, porous dolomite clasts that are surrounded in this case by coarse, low-porosity saddle dolomites. These white dolomites were probably filling space between possible "hydrofractured" replacement dolomites. The black porous dolomites are mostly rhombic (planar) dolomites coated with thin films of pyrobitumen. Width of thin section is 2.5 cm.



2a. Core photo showing a dolomitized interval with distinct light and dark gray to black banding which crudely resembles "zebra structure." The lighter portions of this rock are tight replacement dolomites while the dark gray and black areas are porous rhombic and saddle dolomites lined with pyrobitumen films. In addition, note the swarms of fractures marked by black, porous dolomite.

2b. Entire thin section overview of micro-banded bluish white and black dolomites that has the appearance of small scale "zebra structure." The black bands consist of porous, coarse dolomites (both rhombic and saddle varieties) that are coated with thin films of bitumen. The bluish white bands are composed of coarse dolomite and late calcite with some microporosity. Width of thin section is 2.5 cm.